Tertiary Non-marine Diatoms from Eastern Australia: Descriptions of Taxa

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Non-marine diatomites from eleven localities in New South Wales and southeastern Queensland, ranging in age from Late Oligocene to Middle Miocene, have yielded twenty-nine taxa of diatoms (Bacillariophyta) which are figured here. Genera present include *Melosira, Fragilaria, Synedra, Eunotia, Achnanthes, Cymbella, Gomphonema, Navicula, Pinnularia, Stauroneis,* and *Nitzschia. Navicula seminuloides* Hustedt var. *rhombica* Thomas is recognized as a new variety. Effects of diagenetic dissolution and re-deposition of silica on frustular morphology are discussed and illustrated.

Sponge spicules (Porifera: Spongillidae) are present in all diatomites examined and some examples of these are figured.

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INTRODUCTION

Beds of non-marine diatomite and other lake sediments are widely associated with Cainozoic and generally basaltic lavas in eastern Australia (Crespin, 1947). Many of the lavas have been isotopically dated (e.g. Wellman, 1974, 1978; Wellman and McDougall, 1974) enabling relative geological ages to be assigned to deposits that are widely separated geographically. The deposits in New South Wales and south-eastern Queensland that we have investigated (Fig.1), have been assessed geologically by Herbert (1968) and Bonner (1950, 1951, 1953). Skvortzov (1937) detailed the fossil diatom flora from the Middle Flat deposit near Cooma, and Crespin (1947) listed species from most localities. Hill *et al.* (1970) figured three specimens from the south-eastern Queensland deposits.

In this paper we discuss the taxonomy and illustrate the morphology of diatom frustules from selected Oligocene and Miocene diatomites in south-eastern Queensland and New South Wales. The majority of fossil taxa observed are represented in living assemblages, so lessening reliance on the relatively sparse literature on fossil non-marine diatoms (e.g. Andrews, 1971; Abbott and Van Landingham, 1972); our identifications, principally the work of DPT, are based upon reference to European and North American taxonomic works that include both extant and fossil forms (e.g. Hustedt, 1930a, 1959, 1966; A. Schmidt *et al.*, 1874-1959; Patrick and Reimer, 1966, 1975).

Our conclusions on environments of deposition, geological history of non-marine diatoms, and biostratigraphic implications follow in a second paper (Thomas and Gould, 1981). The diatomites were probably formed in slightly eutrophic freshwater lakes.

MATERIALS AND METHODS

Diatomite samples were obtained from adits and cuttings at known localities. Lump samples were removed from exposed surfaces at intervals of 0.1 to 1.0 m and from any layers in between which differed visually from those above and below; an auger was used to obtain samples at some localities. Samples were individually packaged in polythene bags at the time of collection. Each sample was then dissected in the laboratory to obtain subsamples from within it, avoiding contamination from any adhering surface sediments or surficial, living algae.

Subsamples were scraped into a sample tube where ethyl alcohol was added and

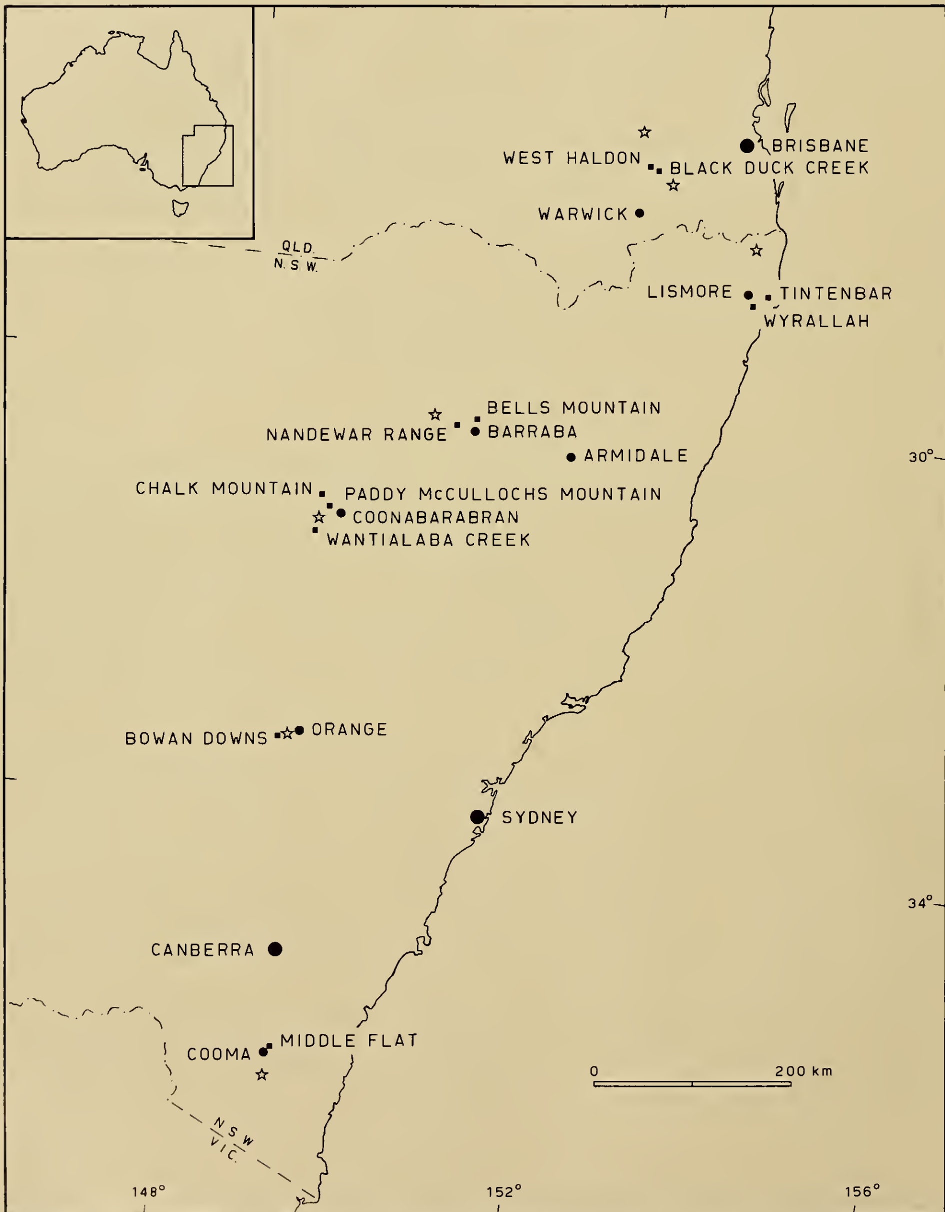

Fig. 1. Locality map. Black squares mark diatomite deposits and stars show centres of volcanic eruption for lavas associated with the diatomites.

the sediment disaggregated using a glass rod. The suspension was then sampled using a pipette to transfer some of the liquid to a cover glass placed upon a hot plate set at 70°C.

For light microscopy the suspension was dried down upon 22 mm diameter, round cover glasses and mounted on a microscope slide using Canada Balsam as the mounting medium. Higher refractive index mounting media, such as HYMOUNT (Gurrs) and NAPHRAX (N.B.S.) were found to be less useful for studying diatoms with the Nomarski Differential Interference Contrast optics employed in this study, though better than Canada Balsam for ordinary transmitted light study. The light microscope slides were scanned with the aid of a ZEISS Photomicroscope III to determine what taxa were present in each sample from each locality.

For scanning electron microscopy the sediment and alcohol suspension was dried down onto 10 mm diameter cover glasses previously coated with colloidal graphite (AQUADAG; Agar Aids) and plated with gold using a sputter coater. These samples were observed using a JEOL JSM-35 scanning electron microscope at the Electron Microscope Unit of the University of New England, Armidale, New South Wales. Some samples for electron microscopy were cleared of organic material prior to being placed in alcohol by warming them in concentrated nitric acid for 12 hours at 60°C (Crawford, 1971) followed by dilution using distilled water and resuspension in ethyl alcohol. This had the advantage of also removing some of the clay particles but meant the loss of a proportion of the small diatoms and could not be used for quantitative or semi-quantitative assessment of the diatom assemblages.

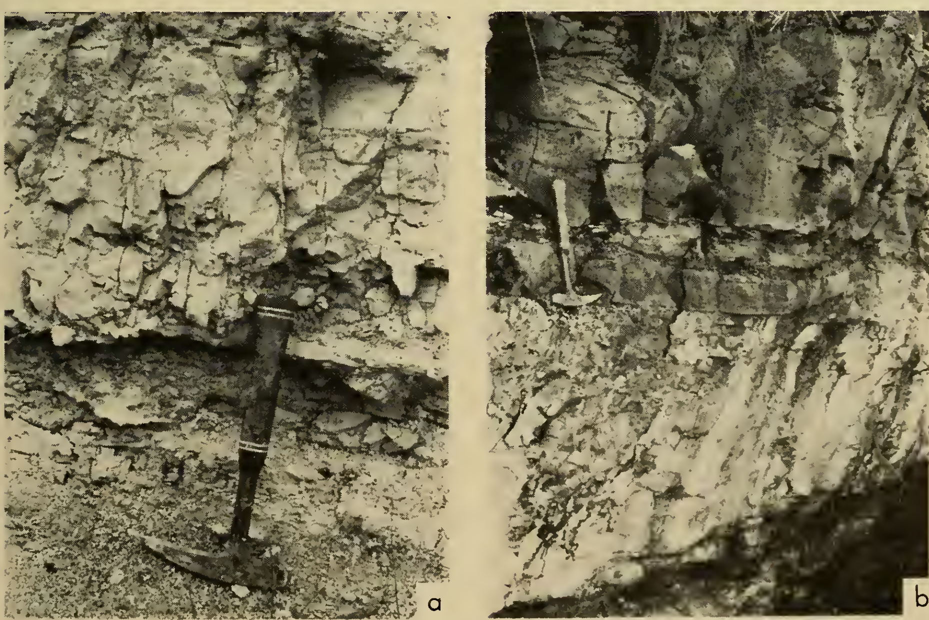

Fig. 2. Diatomite at Bells Mountain north of Barraba.
(a) Base of diatomite deposit (from butt of hammer handle and above) overlying fine-grained lacustrine sediments, to south of Bells Mountain.
(b) Exposure of top of diatomite in collapsed roof of mine, north-north-western side of Bells Mountain; head of hammer at top of diatomite, overlain by tuff (shank of hammer) and basaltic lava (butt of hammer handle).

LOCALITIES

Deposits sampled included those at West Haldon and Black Duck Creek in Queensland, Tintenbar and Wyrallah near Lismore, Bells Mountain and Nandewar Range near Barraba, Paddy McCullochs Mountain, Chalk Mountain (Bugaldie), and Wantialaba (or Wantial) Creek, all near Coonabarabran, Bowan Downs near Orange, and Middle Flat near Cooma, New South Wales (Fig. 1). Some details for each locality are listed here, including a grid reference for the appropriate 1:250 000 topographic sheet, and radiometric ages for associated lavas from Webb *et al.* (1967), Wellman and McDougall (1974) or Wellman (1978). Further information on the localities can be obtained from Bonner (1950, 1951, 1953), Herbert (1968), and Mumme *et al.* (1975).

West Haldon. On tributary of Sandy Creek at Ipswich 516552; interbedded with the Late Oligocene, lower, basaltic portion of the Main Range Volcanics (Cranfield *et al.*, 1975); radiometric age 24-23 m.y; small disused adit.

Black Duck Creek. South of Rocky Shrub Creek at Ipswich 525548; Late Oligocene, similar horizon to West Haldon; currently mined.

Tintenbar. Disused Snow Queen Mine, Milne's Hill, south of Teven-Tintenbar road at Tweed Heads 667427; interbedded with Lismore Basalt (Duggan and Mason, 1978) which lies between Early Miocene units dated at 22.4 and 20.8 m.y.

Wyrallah. Disused mine, corner Hensons and Rous Road, east of Wyrallah, Tweed Heads 648418; Early Miocene, horizon the same as Tintenbar.

Bells Mountain. Disused mines just east of Barraba-Bingara road, Manilla 358252; immediately underlies basaltic lava and tuff (Fig. 2) of the Nandewar Mountains (Wilkinson *et al.*, 1969) assigned a Miocene age of 18 m.y.

Nandewar Range. Sequence along Barraba-Mount Kaputar road, west of Little Creek, at Manilla 337245; Miocene, similar horizon to Bells Mountain.

Paddy McCullochs Mountain. Hill-top sequence overlying Mesozoic sediments, west of Coonabarabran-Baradine road near Yearinan, Gilgandra 207140; overlain by flows from the Miocene Warrumbungle Volcano (Wilkinson *et al.*, 1969) of 16-15 m.y.; small, disused workings.

Chalk Mountain. Currently mined deposit west of Coonabarabran-Baradine road at Bugaldie, Gilgandra 199148; interbedded with lavas from the Miocene Warrumbungle Volcano of 16-15 m.y., at a somewhat similar horizon to Paddy McCullochs Mountain.

Wantialaba Creek. Small deposit in creek bank south of Newell Highway, Gilgandra 197108; interbedded with flows and tuffs from the Miocene Warrumbungle Volcano of about 15-14 m.y.

Bowan Downs. Disused mines west of Orange-Cargo road, at Bathurst 185876; interbedded with basaltic flows of the Middle Miocene Canobolas Volcanic Complex of 12-11 m.y.

Middle Flat. Old workings, currently being opened up for production, at Middle Flat on western side of Middle Flat Creek, Bega 221533. The deposit overlies Palaeozoic sediments, with nearby basaltic rocks of at least 39 m.y. old, or Eocene age; however it

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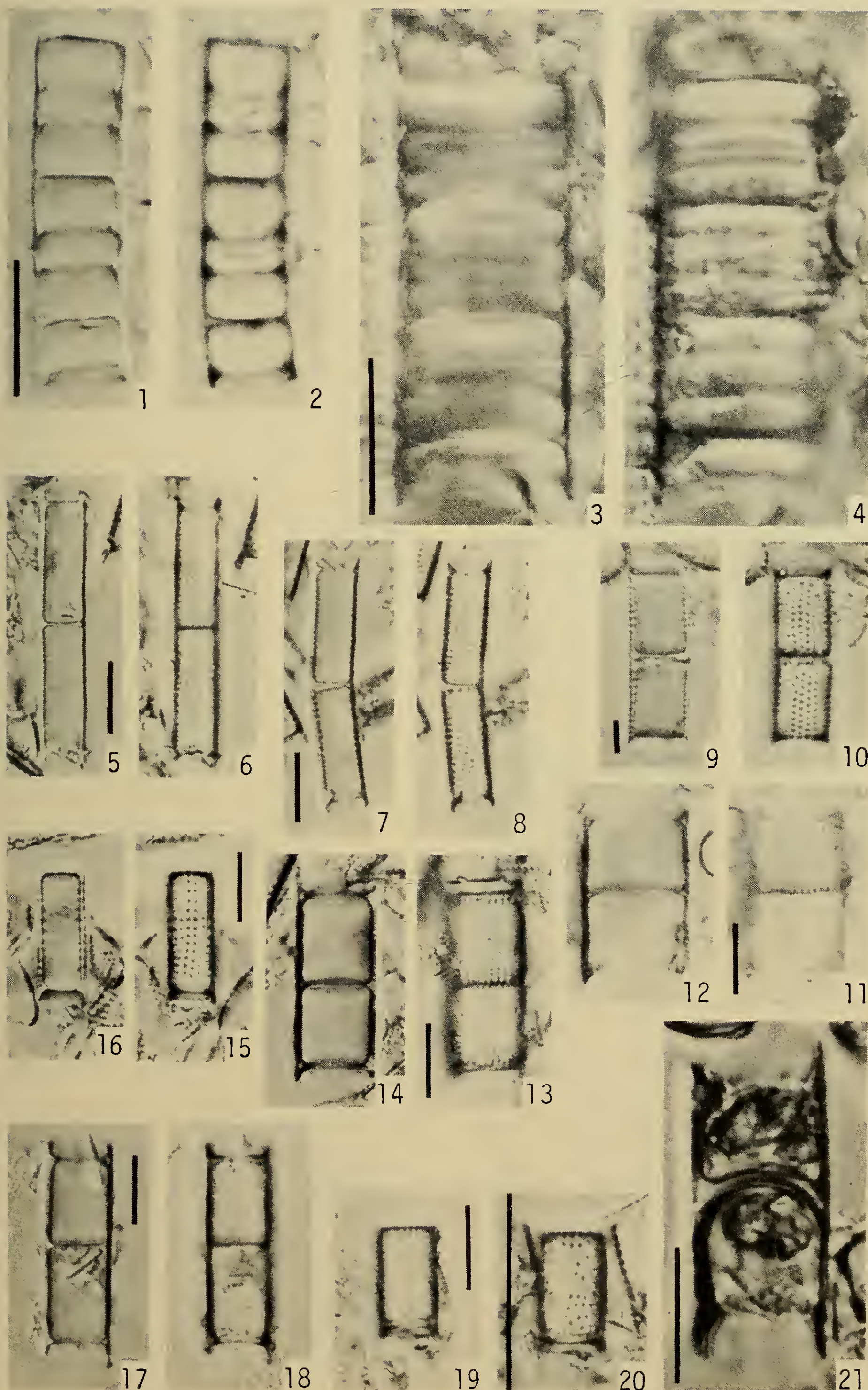
Fig. 3. 1-4. *Melosira* sp. A. 1,2, UNEF15646, Bells Mountain, girdle view of narrower frustules. 3,4, UNEF15648, Bells Mountain, girdle view of broader frustules.

5-21. *Melosira granulata*. 5,6,11-20, UNEF15801a-g, Bowan Downs; 7-10, UNEF15814a, b, Middle Flat. 5-16 show range of valve length to breadth ratios and areola size and distribution. 17-20, valves with irregular and sparse areolation. 21, UNEF15569a, Tintenbar, showing distortion of valve features probably due to mobilization of silica.

Transmitted light micrographs, Nomarski DIC; all scale bars 10 μm, 1-18 paired micrographs of outline and surface foci.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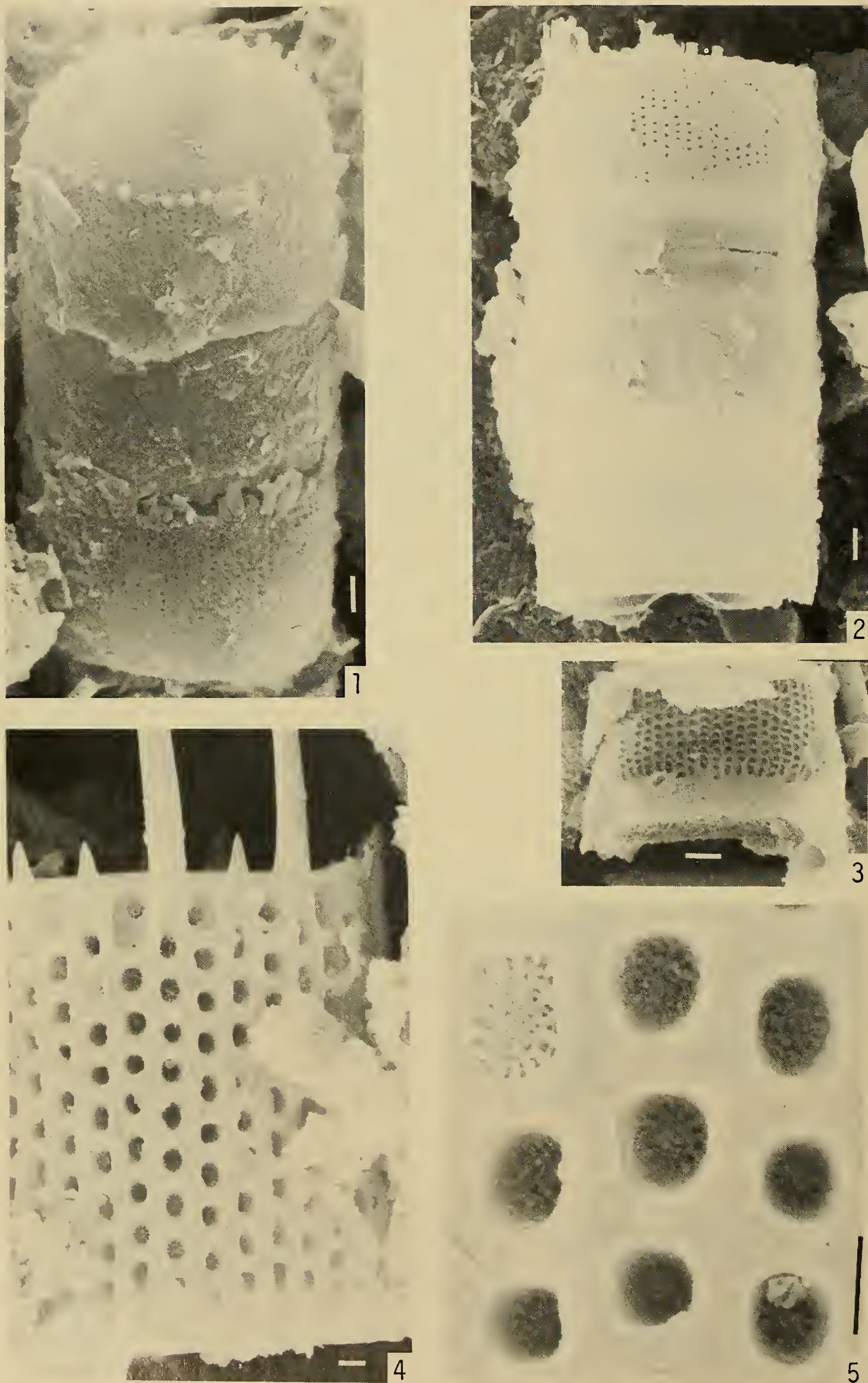
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appears the basalt does not actually overlie the diatomite and so the exact age of the deposit is open to question, but we believe it to be no older than the Black Duck Creek deposit.

Systematic Section

Introduction. The Australian diatom flora, both fossil and living, has been little studied with few published works (e.g. Crosby and Wood, 1958, 1959; Foged, 1978; Wood, 196la, b, 1963; Wood *et al.*, 1959) and very few papers dealing with non-marine fossils (e.g. Skvortzov, 1937). Identification of Australian taxa has therefore to rely on European and North American works and on literature based indexes (e.g. Mills, 1933-1935; Van Landingham, 1967-1979).

There is no implication that taxa which have not been identified to specific level here are new species, but we are unable to ascertain whether they have been described in some of the vast, extra-Australian diatom literature as yet unavailable to us. These taxa have been given an alphabetic code name, rather than add further, perhaps unnecessary, names to an over-crowded diatom systematics.

Taxomonic slides together with slides representative of each sample locality (designated with prefix UNEF), are held in the Geology Department, University of New England, Armidale, New South Wales. Duplicate taxonomic slides of all taxa have been lodged in the phycology herbarium, Botany Department, University of Adelaide, South Australia, and the British Museum (Natural History), London, by DPT. Taxonomic slides are designated by the prefix ADU-D.

The following notes and descriptions are set out in six phylogenetic groups with genera arranged in alphabetical order within each group. Descriptions and terminology follow the outlines suggested in Anonymous (1975) and Hendey (1964). Where possible, species names follow those considered appropriate by Mills (1933-1935) and Van Landingham (1967-1979) which also contain a full listing of synonyms. The occurrences listed refer to localities investigated in this study only. Where species have been previously described, a listing of the literature upon which the identification is based follows the name and precedes any listing of synonymy.

I. Suborder COSCINODISCINEAE

MELOSIRA C. Agardh, 1824

Melosira species A

Fig. 3, 1-4; Fig. 4, 1-3.

Occurrence. Bells Mountain, Nandewar Ra. and Bowan Downs.

Description. Frustule: outline in girdle view square-rectangular. Length of pervalvar axis 8.5 — 11.0 μm. Growth habit: brief colonies of cells attached by interdigitating spines at the margin. Girdle: valvocopular open, non-ligulate, maternal girdle not observed. All bands observed were too corroded for further structure to be elucidated. Two bands observed per frustule. Valve: outline circular, mantle cylindrical with parallel sides, valve face slightly convex. Diameter 6.4 — 10.0 μm. Majority of valve face apparently unpunctured but covered with broad, small granules. Radially directed punctate striae form a marginal ring extending towards the centre for 0.25 of

Fig. 4. 1-3, *Melosira* sp. A. 1, oblique surface view of vegetative valves. 2, girdle view of one vegetative and two separation valves showing the characteristic spine morphologies. 3, interior girdle view of valve showing section through pseudoseptum.
4,5, *Melosira granulata.* 4, girdle view of separation cell with typical spines. 5, detail of same valve showing outer and inner cribra and surface granules.
Scanning electron micrographs; all scale bars 1 μm. All specimens from Bells Mountain.

the radial distance. Mantle with punctate striae extending down to the pseudoseptum but not below. Striae composed of a single row of small puncta and formed between costae parallel to the pervalvar axis on the inner surface of the valve. Striae 28-31/10 μm, puncta 35-58/10 μm. Striae and puncta invisible in the light microscope. Labiate and strutted processes absent. Spines located at the valve margin and directed parallel to the mantle. Vegetative cells have ligulate spines, 1.0 — 1.1 μm long and 0.30 — 0.32 μm wide with bilobate apices. Separation valves have triangulate spines, 1.0 — 1.1 μm long and 0.5 μm wide at the base. Density of spines: a single ring of 15-18/10 μm. Special structures: a pseudoseptum is formed within 1.0 — 1.5 μm of the open end of the valve and parallel to the valvar plane. The pseudoseptum extends into the valve up to 0.14 of the radial distance.

Remarks. The wall structure, presence of separating cells and the form of spines on both the vegetative and separating cells, indicates that this taxon is closely related to *Melosira granulata* and should be considered as part of that diverse group of freshwater *Melosira* species.

Melosira granulata (Ehrenberg, 1841 (1843)) Ralfs *in* Pritchard, 1861

Fig. 3, 5-21; Fig. 4, 4,5; Fig. 5, 1-5; Fig. 6, 1-4.

Ralfs *in* Pritchard, 1861, p. 820.

Van Heurck (1896), p. 444, pl. 19, fig. 621; Hustedt (1930a), p. 248-250, fig. 104; Hustedt (1930b), p. 87-88, fig. 44; Van Landingham (1964), p. 13-14, pl. 31, figs 15-20, pl. 32, figs 1-20, pl. 33, figs 1-34.

1841 (1843) *Gallionella granulata* Ehrenberg, p.415.

1882 *Melosira granulata* f. *australiensis* Grunow *in* Van Heurck, pl. 87, figs 13, 14, 16.

1908 *Melosira granulata* var. *australiensis* (Grunow *in* Van Heurck) Tempere and Peragallo, 1907-1915, p. 30, No. 51-53.

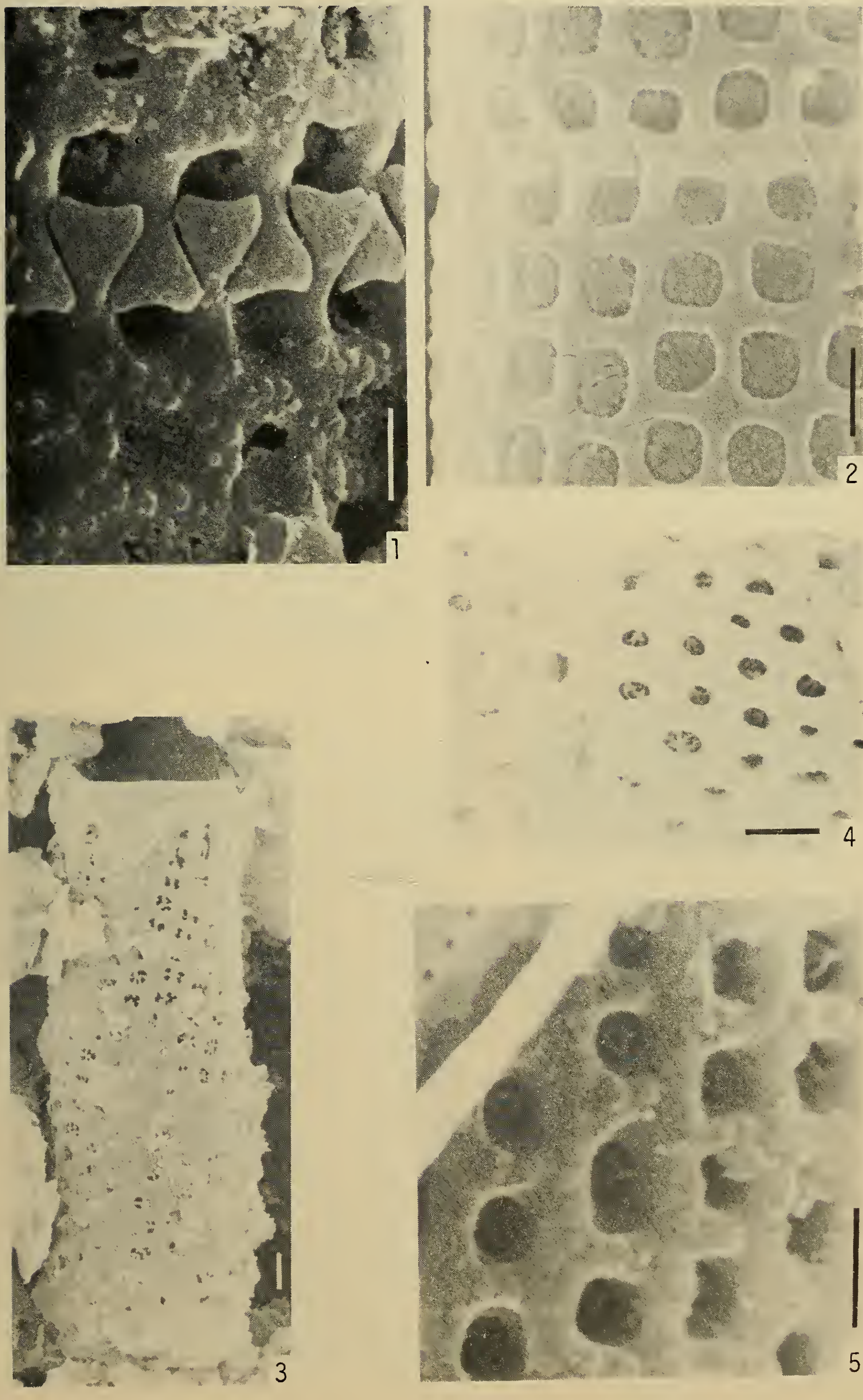
1925 *Melosira polymorpha* subsp. *granulata* (Ehrenberg) Bethge, p. 30.

Occurrence. Found at all the localities from which diatomite was collected.

Remarks. The *M. granulata* observed in the diatomite collections and in fresh material collected from various parts of Australia (see Thomas and Gould, 1981) cause us to agree with the findings of Hustedt (1930a, p. 250) and Florin (1970) that there are two distinct forms of the taxon. In the fossil material these forms are frequently found occurring together (e.g. Fig.3, 13, 15). Hustedt (1930a) nominated them as form α (a large-pored form) and form β (a small-pored form). These do not coincide with the two forms recognized by Crespin (1947) who distinguished a long narrow form and a short broad form. This shape difference has been shown by Kilham and Kilham (1975) to be part of the normal variability of *M. granulata*.

Florin (1970) showed that the large-pored form differs from the small-pored form in the presence of a velum on the external surface of the loculate areola (e.g. Fig. 4, 4-5; Fig. 5, 1-2; see also Akutsu, 1974) whereas the small-pored form has what is more accurately a poroid areola occluded on the inner surface by a velum (e.g. Fig. 5, 3-5). The fossil material observed has both these characteristic forms with the addition that the small-pored form exhibits two types of velum structure. Depending upon the diameter of the areola, in one form the velum varies from a rota through to one or two volae (Fig. 5, 3-4). These may occur anywhere from the inner to the outer

Fig. 5. 1-5, *Melosira granulata.* 1, Bells Mountain, 2, extant, Murray River, South Australia, showing vegetative cell cribrum and spine morphology. 3, Middle Flat. 4,5, Bowan Downs, showing variation in velum morphology in "small-pored" vegetative cells.,
Scanning electron micrographs; all scale bars 1 μm.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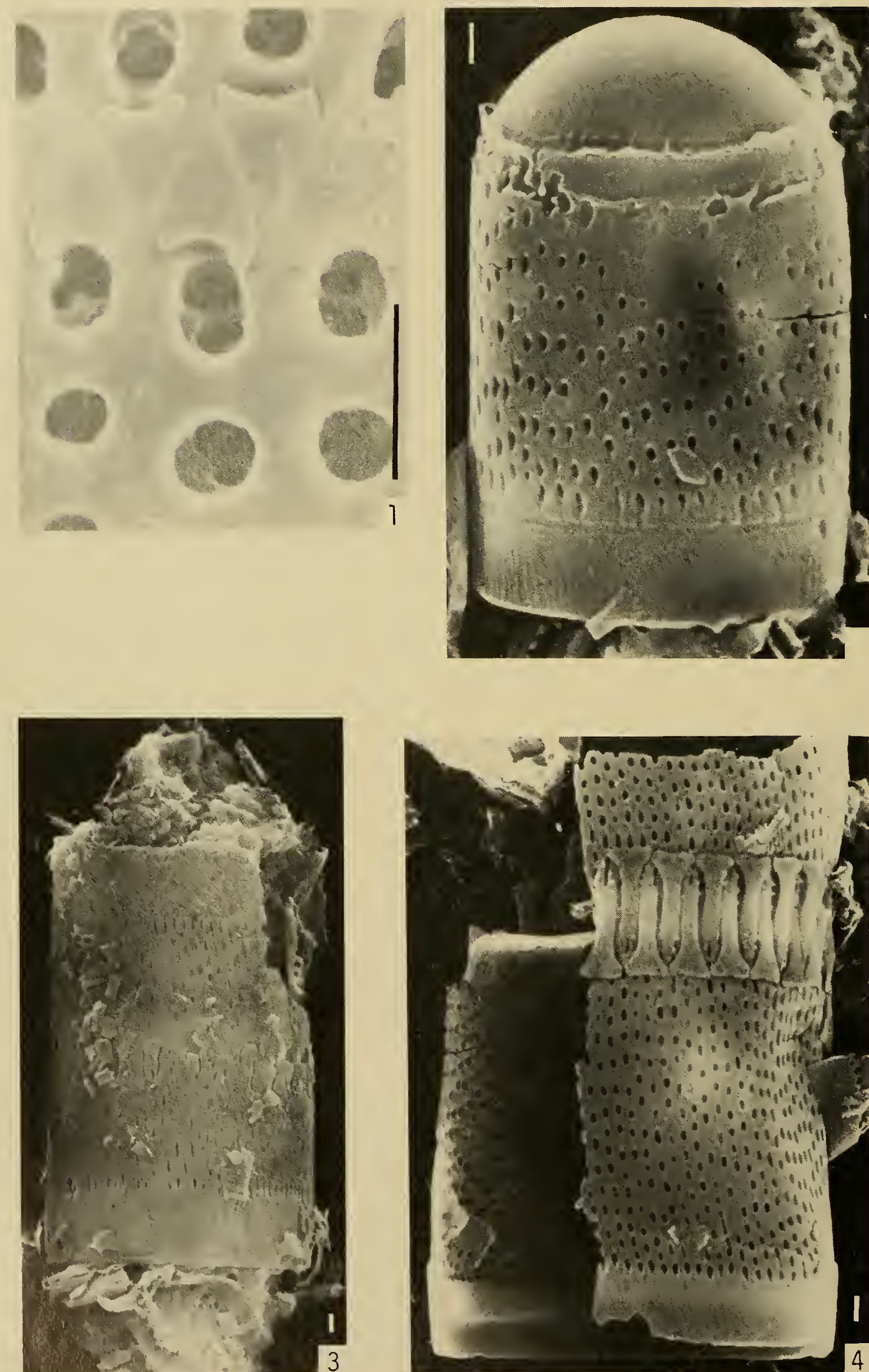
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surface of the valve. In the other small-pored form, the velum has a more complex, three dimensional structure with a cribrum being suspended in the inner opening of the areola by struts which form near the outer opening (Fig. 6, 1). The small-pore form may also be irregularly and sparsely areolate (Fig. 3, 17-20).

The large-pored form has a cribrum at the external opening, as reported by Florin (1970), but has also a cribrum at the inner opening (Fig. 4, 4-5; Fig. 5, 1-2). Both cribra are more ornate on the separation valves (e.g. Fig. 4, 4-5).

A further differentiation occurs in the shape of the spines which hold the ordinary vegetative cells together. This variation does not follow the division based upon areola form. The spine shapes vary from pyriform, with more or less concave apices (see Fig. 5, 1-2), to more or less "T" shaped (see Fig. 6, 4). The pyriform spine is found in both large- and small-pore forms but the "T" shaped spine is found only in the small-pore forms of both velum types.

Identification of the various forms is hampered by the effects of diagenetic mobilization of the silica from the frustules in some samples. This may lead to redeposition on the frustules or corrosion and loss of the silica. If this mobilization only occurs to a minor extent, the velum is lost (e.g. Fig. 6, 4), but in many cases corrosion leads to loss of shape for the spines, variation in the areola size and variation in shape in the valve face (e.g. Fig. 3, 21; Fig. 6, 2-3). If redeposition occurs, then the areolae may become all but filled in to form slits and pores (e.g. Fig. 6, 3).

Finally, there are present in many samples a few valves whose size, shape, and size and distribution of areolae, could cause them to be placed in almost any one of the fifty or more 'species' which belong to this group of *Melosira* and are indicative that this group, so common in freshwater assemblages, is long overdue for taxonomic revision. We agree with Van Landingham (1964, p. 10) in supporting the hypothesis of Bethge (1925) which combines the common species of the *M. granulata* group (*M. granulata, M. islandica, M. ambigua, M. italica, M. distans* and *M. lirata*) into *M. polymorpha* and considers that this may be part of the answer in coping with these numerous species with similar morphology.

Recorded from Oligocene and Miocene diatomites of eastern Australia by Crespin (1947) and Skvortzov (1937).

Melosira granulata var. *curvata* Grunow *in* Van Heurck, 1882

Fig. 7, 1.

Grunow *in* Van Heurck, 1882, pl. 87, fig. 18.

Van Heurck, 1896, p. 444, pl. 19, fig. 622.

1882 *Melosira granulata* f. *curvata* Grunow *in* Van Heurck, pl. 97, fig. 24; Hustedt, 1930a, p. 250.

1930a *Melosira angustissima* f. *curvata* Hustedt, p. 251, fig. 80/7.

Occurrence. Nandewar Range.

Remarks. This taxon is similarly structured to the small-pored form of *M. granulata* with one cribrum formed on or towards the inner surface of each poroid areola. The only difference then being the curvature of the valve.

Melosira undulata var. *spiralis* Skvortzov, 1937

Fig. 9, 1-3.

Skvortzov, 1937, p. 178, figs 23-24.

Occurrence. West Haldon, Black Duck Ck, Tintenbar, Wyrallah, Bells Mountain, Bowan Downs.

Fig. 6. 1-4, *Melosira granulata.* 1, extant, Lake Picton, Tasmania, showing complex velum morphology of vegetative cells. 2-4, Tintenbar, showing effects of diagenetic mobilization of silica.
Scanning electron micrographs; all scale bars 1 μm.

Remarks. Not common in any of the samples collected. Skvortzov (1937) described this taxon from Middle Flat, where it was noted as infrequent; it has not been found in any of the samples collected there during this investigation.

II. Suborder ARAPHIDINEAE

FRAGILARIA Lyngbye, 1819

Fragilaria construens var. *venter* (Ehrenberg, 1854) Grunow *in* Van Heurck, 1881

Fig. 7, 3-5; Fig. 8, 1.

Grunow *in* Van Heurck, 1880-1885, pl. 45, figs 21B-23, 24B, 26A-B.

Van Heurck, 1896, p. 325, fig. 11/451; Hustedt, 1913 *in* A. Schmidt *et al.* 1874-1959, pl. 296, figs 30-33, 47; Hustedt, 1959, p. 158, figs 670h-m.

1854 *Fragilaria venter* Ehrenberg, pl. 8/1, fig. 12, pl. 11/14, pl. 13/1, fig. 4.

Occurrence. West Haldon, Tintenbar, Wyrallah, Bells Mountain, Nandewar Ra., Chalk Mountain, Wantialaba Ck, Middle Flat, Bowan Downs.

Remarks. The distribution of this taxon ranges from Miocene to the present and is found most abundantly in samples containing a high proportion of silt, and may be indicative of periods of high run-off from the surrounding area.

Fragilaria lapponica Grunow *in* Van Heurck, 1881.

Fig. 7, 2; Fig. 9, 4.

Grunow *in* Van Heurck, 1880-1885, fig. 45/35.

Hustedt, 1930b, p. 145, fig. 155; Hustedt, 1959, p. 170-171, fig. 678.

Occurrence. West Haldon, Tintenbar, Wyrallah.

Remarks. Described by Abbott and Van Landingham (1972) as epiphytic and therefore probably indicative of shallow water or the nearness of swamp or marsh land to the lake in which the diatoms were deposited.

Fragilaria leptostauron (Ehrenberg, 1854) Hustedt, 1959

Fig. 8, 3; Fig. 9, 5.

Hustedt, 1959, p. 153-154, figs 668a-f.

1854 *Biblarium leptostauron* Ehrenberg, pl. 12, figs 35-36.

Occurrence. Middle Flat.

Remarks. Found only in a reworked sample from beneath the third dark, clay layer 3.9 m below the roof of the mine and 4.1 m below the overlying basaltic soil, in the northwestern adit figured by Herbert (1968, p. 24).

Fragilaria leptostauron var. *dubia* (Grunow, 1862) Hustedt, 1959

Fig. 9, 6, 7.

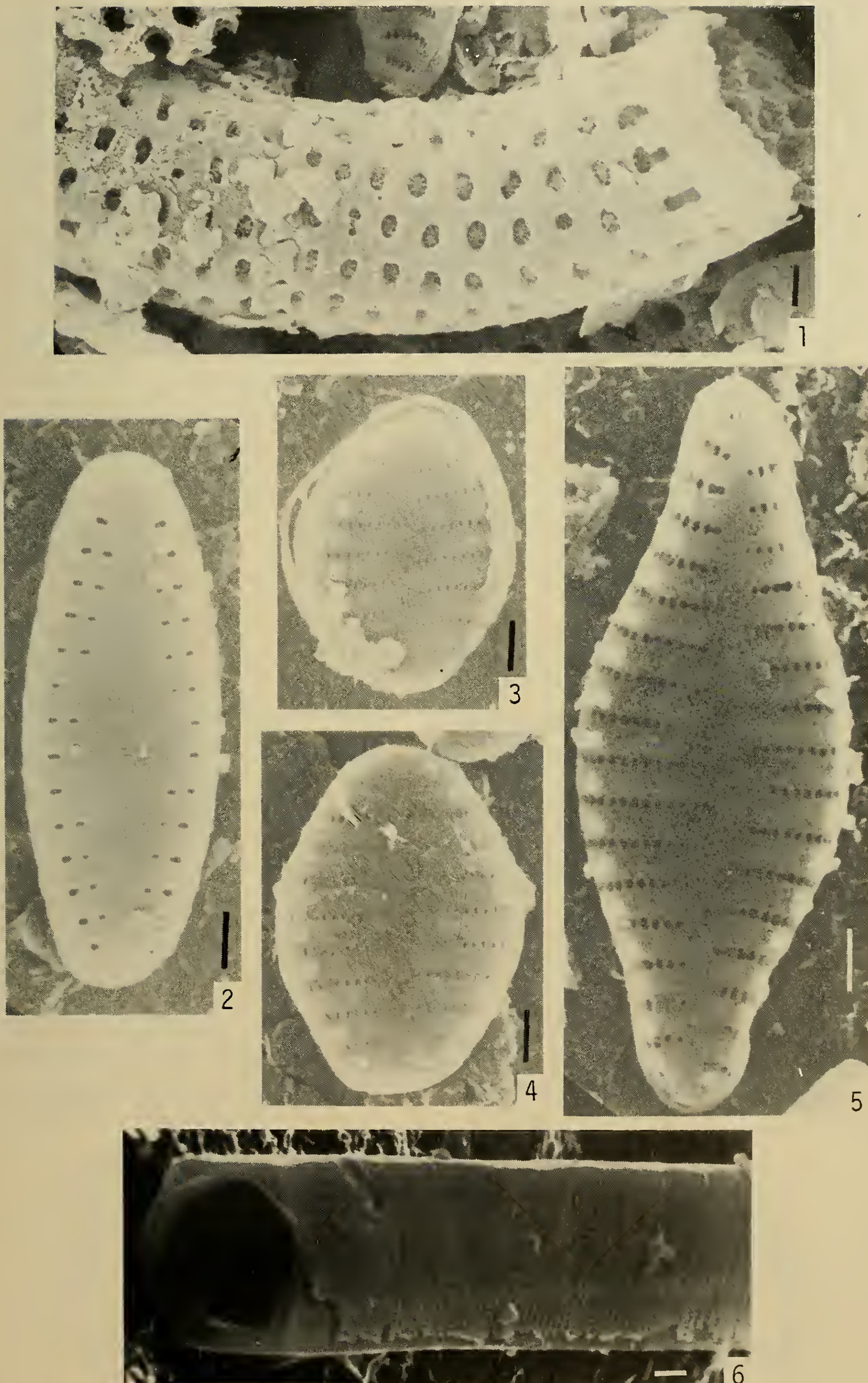
Hustedt, 1959, p. 154-155, figs 668h-i.

1862 *Fragilaria harrisonii* var. *dubia* Grunow, p. 368, pl. 7, figs 8a-d.

Occurrence. Bells Mountain, Nandewar Ra.

Remarks. Occurs rarely in the two localities. Hustedt (1959) describes the habit of this taxon as benthic, commonly found in the littoral region of freshwater bodies.

Fig. 7. 1. *Melosira granulata* var. *curvata*, Nandewar Range, girdle view of vegetative valves.
2. *Fragilaria lapponica*, Tintenbar, valve surface.
3-5. *Fragilaria construens* var. *venter*, West Haldon, valve views showing variation in valve outline with length.
6. Cf. *Synedra* sp., Bells Mountain, oblique view showing girdle morphology and section through frustule.
Scanning electron micrographs; all scale bars 1 μm.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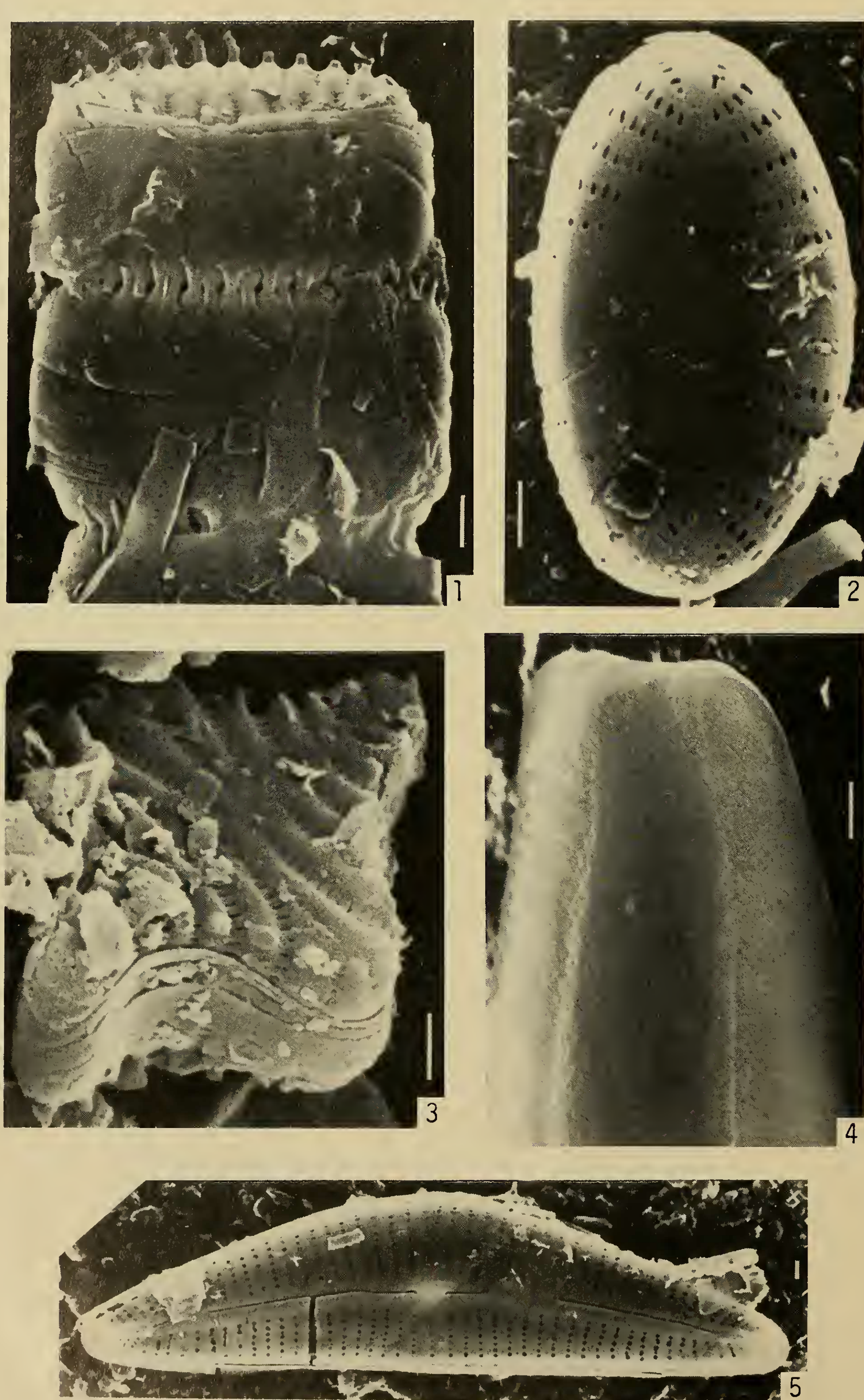
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SYNEDRA Ehrenberg, 1830

Synedra ulna (Nitzsch, 1817) Ehrenberg, 1838

Fig. 9, 8.

Ehrenberg, 1838, pl. 211, pl. 17, fig. 1.

Van Heurck, 1896, p. 310, pl. 10, fig. 409; Hustedt, 1914 *in* A. Schmidt *et al.*, 1874-1959, pl. 301, figs 1-26, pl. 302, figs 1-17, 19-22, pl. 303, figs 1-4; Hustedt, 1930b, p. 151-152, figs 158-159; Hustedt, 1959, p. 195-198, figs 691Aa-c.

1817 *Bacillaria ulna* Nitzsch, p. 99.

Occurrence. West Haldon, Bowan Downs.

Remarks. The form observed varied from that of the typical *S. ulna* to that of *S. ulna* var. *danica*. *Synedra ulna* has been reported from Miocene and younger deposits of Australia by Crespin (1947) and Tindale (1953). Crespin (1947) records *S. ulna* from Tintenbar and Chalk Mountain as well as Bowan Downs but it has not been observed from the first two localities in this study.

cf. *Synedra* sp.

Fig. 7, 6; Fig. 8, 4; Fig. 9, 9.

Occurrence. West Haldon, Tintenbar, Wyrallah, Nandewar Ra.

Description. Frustule: outline in girdle view inflated-linear to very narrow-elliptical with truncated apices. Length of pervalvar axis 2.5-4.2 μm. Girdle apparently absent. Valve: outline; linear, narrowing to an almost rostrate apex. Shape; valve face flat, the mantle extends outwards at an angle of approximately 10-15° to the pervalvar axis. Dimensions; apical axis 25-60 μm, transapical axis 1.7-2.0 μm. Valve structure; valve face appears to have fine, parallel striae when observed in the light microscope but is seen in the scanning electron microscope to be unpunctured on the external surface and punctured by two parallel rows of pores on the inner surface. The inner pores are apparently connected to the exterior of the valve by tunnels in the valve wall which open externally towards the outer edge of the mantle where punctate striae occur. Striae 45-47/10 μm, puncta 50-65/10 μm. Pore fields and processes absent.

Remarks. This taxon looks like a freshwater sponge spicule when seen under low power in the light microscope but appears more like a diatom at high power and in the electron microscope. The structure of the valve does not readily imply that the form should be placed into *Synedra* but it is more closely related in form to *Synedra* than to any other diatom genus and the possibility exists that this may be a resting spore of one of the *Synedra* species.

III. Suborder RAPHIDOIDINEAE

EUNOTIA Ehrenberg, 1837

Eunotia pectinalis (Dillwyn, 1809 *ex* Kützing, 1844) Rabenhorst, 1864

Fig. 9, 10, 11; Fig. 13, 5.

Rabenhorst, 1864, p. 73.

Van Heurck, 1896, p. 300, figs 9/370, 371; Hustedt, 1911 *in* A. Schmidt *et al.* 1874-1959, pl. 271, figs 10, 11, 15; Hustedt, 1959, p. 296, figs 763a, k.

1809 *Conferva pectinalis* Dillwyn, pl. 24.

Fig. 8. 1. *Fragilaria construens* var. *venter*, West Haldon, girdle view.
2. *Achnantes* sp. A, West Haldon, araphic valve view.
3. *Fragilaria leptostauron*, Middle Flat, oblique view of frustule showing surface features.
4. Cf. *Synedra* sp., Tintenbar, oblique view of frustule polar region; note lack of perforation on the external surface of the valve face.
5. *Cymbella cistula* var. *maculata*, West Haldon, valve view; note slight enlargement of puncta due to dissolution of the silica.
Scanning electron micrographs; all scale bars 1 μm.

1844 *Himantidium pectinale* (Dillwyn, 1809) Kützing, p. 39, pl. 16, fig. 11.
Occurrence. West Haldon, Black Duck Ck, Tintenbar, Wyrallah, Bells Mountain, Nandewar Ra., Chalk Mountain, Wantialaba Ck, Bowan Downs.
Remarks. The form observed here covers the range from *E. pectinalis* to *E. pectinalis* var. *minor* and *E. pectinalis* var. *minor* f. *intermedia*. Skvortzov (1937) recorded the very similar species *E. valida* from the Middle Flat deposit but no *Eunotia* species have been observed from that locality in this study.

IV. Suborder MONORAPHIDINEAE

ACHNANTHES Bory, 1822

Achnanthes sp. af. *atomus* Hustedt, 1937

Fig. 10, **7, 8**.

Hustedt, 1937, p. 194-195, pl. 13, figs 33-36.

Occurrence. West Haldon, Tintenbar.
Remarks. This form differs from *A. atomus* in being lanceolate instead of linear and is hence wider (6.3-6.8 μm *vs* 2.5-3.0 μm) and in having a lower strial density (14-15/10 μm *vs* 22-25/10 μm on the araphic valve; 18-20/10 μm *vs* 28-30/10 μm on the raphic valve).

Achnanthes lanceolata (Brébisson *in* Kützing, 1849) Grunow *in* Cleve and Grunow, 1879

Fig. 9, **12**; Fig. 10, **1, 2**.

Cleve and Grunow, 1879, p. 23.

Van Heurck, 1896, fig. 8/336; Hustedt, 1959, p. 408-409, fig. 863.
1849 *Achnanthidium lanceolatum* Brébisson *in* Kützing, p. 54.
Occurrence. West Haldon.
Remarks. Reported from other fossil deposits in Australia by Tindale (1953). Foged (1978) collected this species from rivers and creeks with both stagnant and running waters.

Achnanthes sp. af. *lapidosa* Krasske, 1929

Fig. 10, **9, 10**.

Krasske, 1929, p. 350.

Occurrence. West Haldon, Tintenbar, Wyrallah, Bells Mountain, Nandewar Ra.
Remarks. This form differs from *A. lapidosa* in being slightly larger (length 25-28 μm *vs* 20-24 μm) and more lanceolate than linear-lanceolate. In addition the central area is more restricted than is indicated by the illustration in Hustedt (1959, fig. 852a-c).

Fig. 9. **1-3**. *Melosira undulata* var. *spiralis*, West Haldon. **1,2**, UNEF15623a, outline and surface foci of girdle view. **3**, UNEF15619, valve view.
4. *Fragilaria lapponica*, UNEF15566, Wyrallah, valve view.
5. *Fragilaria leptostauron*, UNEF15836, Middle Flat, valve view.
6,7. *Fragilaria leptostauron* var. *dubia*. **6**, UNEF15731, Nandewar Range, **7**, UNEF15799, Bowan Downs, showing range of valve outline.
8. *Synedra ulna*, UNEF15811, Bowan Downs, fragment of valve.
9. Cf. *Synedra* sp., UNEF15569b, Tintenbar, girdle view.
10-11. *Eunotia pectinalis*. **10**, UNEF15580a, Tintenbar, **11**, UNEF15694, Bells Mountain, showing range of size and morphology.
12,13. *Achnanthes lanceolata*, UNEF15635a, West Haldon. **12**, raphic valve view. **13**, araphic valve view.
Transmitted light micrographs, Nomarski DIC; all scale bars 10 μm.

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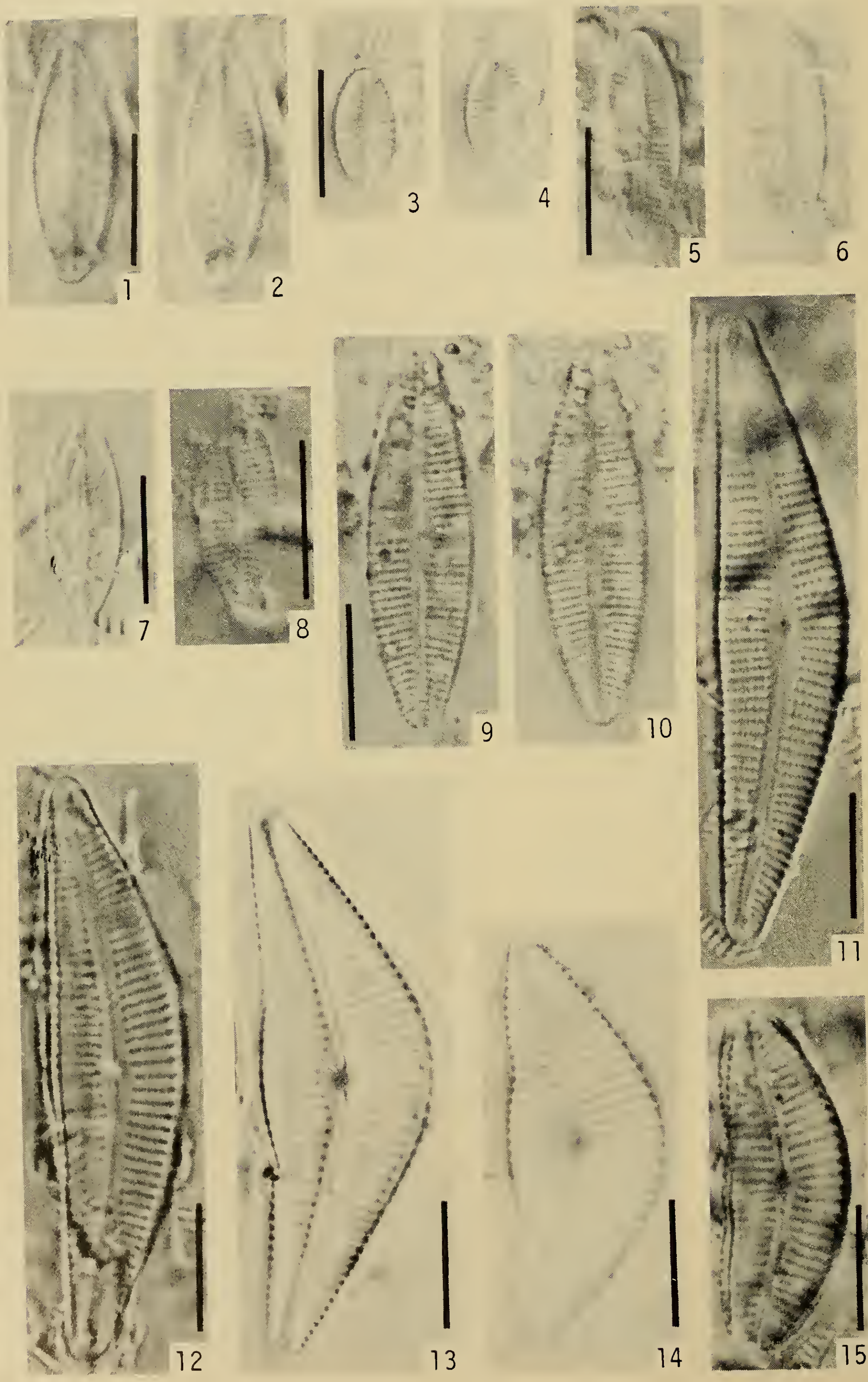
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Achnanthes species A
Fig. 8, 2: Fig. 10, 3, 4.

Occurrence. West Haldon.
Description. Valve: outline elliptical-lanceolate. Apical axis 7.8–9.8 μm, transapical axis 4.0–4.9 μm. Raphic valve with narrow axial area and small circular to lanceolate central area. Araphic valve with narrow axial area and large central area, semilanceolate on one side and extending to the margin on the other side. Central area 3.0–3.5 μm long. Axial areas of both valves straight and situated on the midline of the valve. Striae radiate, less dense opposite the central area on the raphic valve. Density of striae 15-16/10 μm on the raphic valve, 14-18/10 μm on the araphic valve. Striae composed of slits formed parallel to the margin. Slits 52-58/10 μm of stria. Pore fields absent. Processes absent. Raphe located in the axial area, straight. Length of central node 1.0 μm.

Achnanthes species B
Fig. 10, 5, 6.

Occurrence. West Haldon.
Description. Valve: outline broad-elliptical to almost lanceolate. Apical axis 16.0–17.5 μm, transapical axis 6.0–6.3 μm. Axial area of both valves narrow-linear and situated on the midline of the valve. Central area on both valves narrow, delimited by one brief stria on either side of the mid-point of the valve. Striae straight and radiate. Strial density 16-18/10 μm on the raphic valve, 16-17/10 μm on the araphic valve. Pore fields and processes absent. Raphe located in the centre of the axial area, straight. Central node 0.8–0.9 μm long.

V. Suborder BIRAPHIDINEAE
Superfamily NAVICULACEAE
CYMBELLA C. Agardh, 1830
Cymbella cistula var. *maculata* (Kützing, 1833) Van Heurck, 1880-1885.
Fig. 8, 5; Fig. 10, 11-15; Fig. 11, 1.
Van Heurck, 1880-1885, p. 64, fig. 2/16.

A. Schmidt *et al.*, 1874-1959, pl. 71, figs 21-22; Hustedt, 1930b, p. 363, fig. 676b; Van Landingham, 1964, p. 46, pl. 21, fig. 5.
1833 *Frustulia maculata* Kützing, p. 11, fig. 4
Occurrence. West Haldon, Black Duck Ck, Tintenbar, Wyrallah, Bells Mountain, Nandewar Ra., Bowan Downs.
Remarks. This taxon has been recorded previously from the eastern Australian diatomites under the name of the co-occurring *C. ventricosa* by Crespin (1947) and was illustrated by Hill *et al.* (1970) from the Black Duck Creek deposit. This would appear to be an epiphyte species and is indicative of shallow waters somewhere in the area of deposition.

Fig. 10. 1,2. *Achnanthes lanceolata*, UNEF15635b, West Haldon. 1, raphic valve view, 2, araphic valve view.
3,4. *Achnanthes* sp. A, UNEF15598, West Haldon. 3, raphic valve view. 4, araphic valve view.
5,6. *Achnanthes* sp. B, UNEF15605, West Haldon. 5, raphic valve view. 6, araphic valve view.
7,8. *Achnanthes* sp. af. *atomus*, Tintenbar. 7, UNEF15580b, raphic valve view. 8, UNEF15582, araphic valve view.
9,10. *Achnanthes* sp. af. *lapidosa*, UNEF15554, Wyrallah. 9, raphic valve view. 10, araphic valve view.
11-15. *Cymbella cistula* var. *maculata*, West Haldon. 11,12,15, UNEF15587a,b,c, 13, UNEF15625a, 14, UNEF15631a, showing variation in valve morphology with size.
Transmitted light micrographs, Nomarski DIC; all scale bars 10 μm.

Cymbella ventricosa C. Agardh, 1830
Fig. 11, 2; Fig. 12, 1-5.
Agardh, 1830, p.9.

A. Schmidt *et al.*, 1874-1959, pl. 9, fig. 32, pl. 72, fig. 11; Hustedt, 1930b, p. 359, fig. 661; Van Landingham, 1964, p. 47, pl. 23, figs 1-39.

Occurrence. West Haldon, Black Duck Ck, Bells Mountain, Nandewar Ra., Chalk Mountain, Bowan Downs.

Remarks. Recorded from Australian fossil deposits by Crespin (1947) and Tindale (1953). A tube-dwelling, epiphytic taxon more indicative of shallow streams and creeks than of lakes or ponds.

GOMPHONEMA C. Agardh, 1824
Gomphonema intricatum Kützing, 1844
Fig. 11, 3.
Kützing, 1844, p. 87, fig. 9/4.

Van Heurck, 1896, p. 273, fig. 7/313; A. Schmidt, 1874-1959, pl. 234, figs 47-50, 58, pl. 235, figs 15-17, 34-39, pl. 236, figs 1-8, pl. 247, figs 34-38, pl. 248, figs 23-25; Hustedt, 1930b, p. 375, fig. 697.

Occurrence. West Haldon, Black Duck Ck, Tintenbar, Wyrallah, Nandewar Ra., Chalk Mountain, Wantialaba Ck, Middle Flat, Bowan Downs.

Remarks. Crespin (1947) recorded *G. intricatum* from Wyrallah and Tindale (1953) recorded it from some of the deposits in Victoria. Skvortzov (1937) recorded a similar species, *G. longiceps* var. *subclavata* (= *G. montanum* var. *subclavatum* Grunow *in* Van Heurck, 1880-1885) from the Middle Flat deposit.

NAVICULA Bory, 1822
Navicula amphibola Cleve, 1891
Fig. 12, 6.
Cleve, 1891, p. 33.

Cleve, 1894, p. 45; A. Schmidt *et al.*, 1874-1959, pl. 244, fig. 15, pl. 398, figs 20-22; Hustedt, 1966, p. 792-795, fig. 1767.

Occurrence. West Haldon, Tintenbar, Wyrallah, Nandewar Ra., Wantialaba Ck, Bowan Downs.

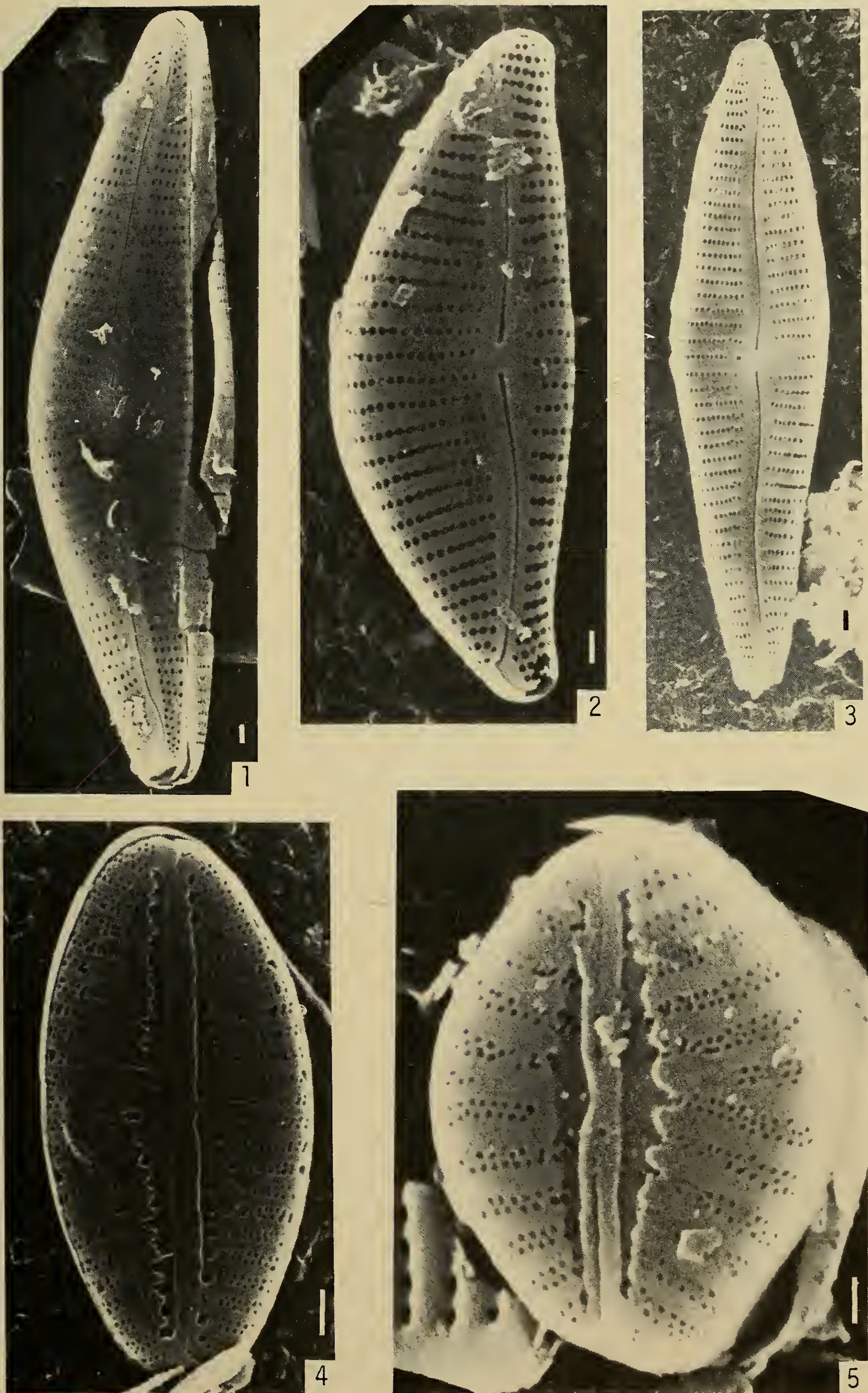
Navicula sp. af. *laterostrata* Hustedt, 1925
Fig. 12, 11.
Hustedt, 1925, p. 349, fig. 4.

Hustedt, 1966, p. 146, fig. 1279.

Occurrence. West Haldon, Bells Mountain.

Remarks. This form differs from the type in being elliptical-lanceolate in valve outline and having a lower density of striae opposite the central area.

Fig. 11. 1. *Cymbella cistula* var. *maculata*, West Haldon, oblique valve view; note the pore field at each pole.
2. *Cymbella ventricosa*, West Haldon, valve view; note effect of dissolution on punctum diameter and raphe.
3. *Gomphonema intricatum*, Tintenbar, valve view; pore field at basal pole damaged and incomplete.
4. *Navicula seminuloides*, West Haldon, valve view.
5. *Navicula seminuloides* var. *rhombica* Thomas var. nov., West Haldon, valve view.
Scanning electron micrographs; all scale bars 1 μm.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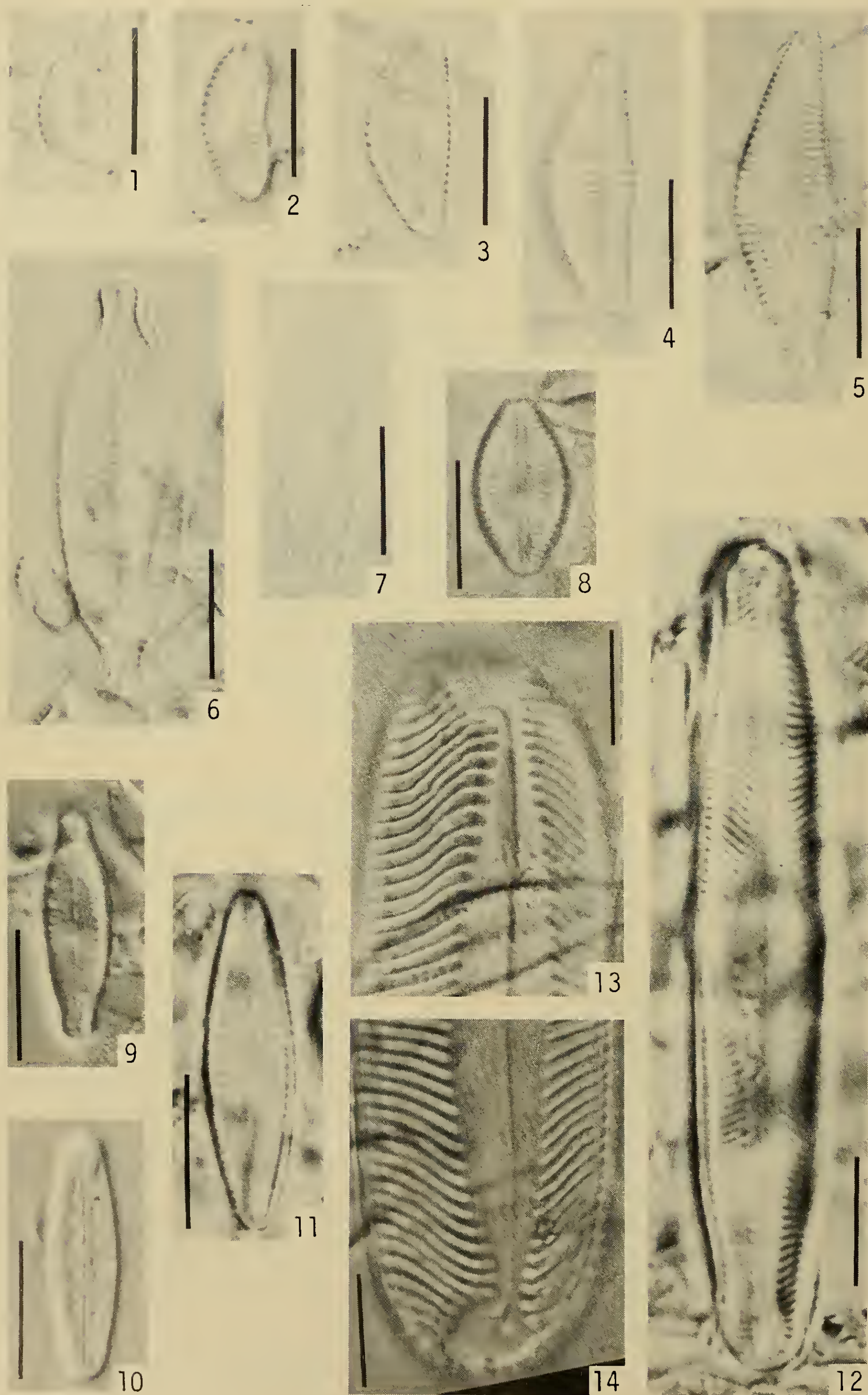
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Navicula naumannii Hustedt, 1942
Fig. 12, 9.
Hustedt, 1942, p. 115, figs 22-24.
Hustedt, 1966, p. 96-97, fig. 1243.
Occurrence. Tintenbar.

Navicula sp. af. *perpusilla* Grunow, 1860
Fig. 12, 10.
Grunow, 1860, p. 552, pl. 4, fig. 7.
Occurrence. West Haldon, Tintenbar.
Remarks. This form differs from the type by having a lower strial density (16-17/10 μm *vs* 36 or more/10 μm).

Navicula seminuloides Hustedt, 1936 *in* A. Schmidt *et al.*, 1874-1959
Fig. 11, 4; Fig. 12, 7.
Hustedt, 1936 *in* A. Schmidt *et al.*, 1874-1959, pl. 401, figs 68-71.
Hustedt, 1966, p. 244-245, fig. 1369.
Occurrence. West Haldon, Tintenbar, Wyrallah, Bells Mountain.
Remarks. Described by Hustedt (1966) as a tropical freshwater form.

Navicula seminuloides var. *rhombica* Thomas var. nov.
Fig. 11, 5; Fig. 12, 8.
Varietal Type: UNEF15611, figured in Fig. 12, 8.
Occurrence. West Haldon.
Remarks. This form differs from *N. seminuloides* in having a broad-rhombic valve outline with rounded to slightly rostrate apices. Over a period of approximately 2000 years this form diverged from the typical *N. seminuloides*, which dominated some of the earlier assemblages, replaced *N. seminuloides* as the dominant taxon, and eventually disappeared from the assemblage to be replaced by *N. seminuloides* again (see Thomas and Gould, 1981, fig. 3G). This appears to have been an entirely localized variation and hence has been given a name, in defiance of the general policy stated in the introduction to this section.

PINNULARIA Ehrenberg, 1840
Pinnularia graciloides Hustedt, 1936 *in* A. Schmidt *et al.*, 1874-1959
Fig. 12, 12.
Hustedt, 1936 *in* Schmidt *et al.*, 1874-1959, pl. 406, "Berichtigungen".
1934 *Pinnularia gracilis* Hustedt *in* A. Schmidt *et al.*, 1874-1959, pl. 392, figs 2-3.

Fig. 12. 1-5. *Cymbella ventricosa*, West Haldon. 1,5, UNEF15629a,b, 2, UNEF15634, 3,4, UNEF15626a,b, showing variation in valve morphology with size.
6. *Navicula amphibola*, UNEF15623b, West Haldon, valve view.
7. *Navicula seminuloides*, UNEF15631b, West Haldon, valve view.
8. *Navicula seminuloides* var. *rhombica* Thomas var. nov., varietal type, UNEF15611, West Haldon, valve view.
9. *Navicula naumannii*, UNEF15580c, Tintenbar, valve view.
10. *Navicula* sp. af. *perpusilla*, UNEF15580d, Tintenbar, valve view.
11. *Navicula* sp. af. *laterostrata*, UNEF15600, West Haldon, valve view.
12. *Pinnularia graciloides*, UNEF15636, West Haldon, valve view.
13,14. *Pinnularia* sp. af. *major*, UNEF15587d, West Haldon, polar views of specimen illustrated in Fig. 13, 3. 13, external focus. 14, internal focus of opposite pole.
Transmitted light micrographs, Nomarski DIC; all scale bars 10 μm.

Occurrence. West Haldon, Tintenbar, Bells Mountain, Nandewar Ra., Bowan Downs.
Remarks. An uncommon taxon which is very similar to the common freshwater species *P. microstauron* and may be easily misidentified as such.

Pinnularia sp. af. *major* (Kützing, 1833) Rabenhorst, 1853
Fig. 12, 13, 14; Fig. 13, 1-3.
Rabenhorst, 1853, p. 42, pl. 6, fig. 5.

1833 *Frustulia major* Kützing, p. 547, pl. 14, fig. 25.
Occurrence. Found in samples from all localities.
Remarks. These specimens differ from the type in having striae which are more convergent near the poles, where they are almost sigmoid. In addition a stigma is present level with the central node end of each raphe slit and on the side of the axial area towards which the terminal fissure veers. This form was recorded by Crespin (1947) as *P. major.*

STAURONEIS Ehrenberg, 1841
Stauroneis frauenfeldiana (Grunow, 1868) Heiden, 1903 *in* A. Schmidt *et al.*, 1874-1959
Fig. 14, 1.

Heiden, 1903 *in* A. Schmidt *et al.,* 1874-1959, pl. 242, fig. 19.
1868 *Pleurostauron frauenfeldianum* Grunow, p. 21, pl. 1, figs 13a-d.
1937 *Stauroneis playfairiana* Skvortzov, p. 179, fig. 21.
Occurrence. West Haldon, Tintenbar, Wyrallah, Bells Mountain, Nandewar Ra., Chalk Mountain, Middle Flat, Bowan Downs.
Remarks. Foged (1978) noted the present occurrence of this species as rare, but this does not apply to its distribution during the Tertiary in eastern Australia. The species described as *S. playfairiana* by Skvortzov (1937) from Middle Flat appears to be a slightly deformed frustule of *S. frauenfeldiana* in that it is illustrated with a slight constriction in the valve outline opposite the central node.

VI. Superfamily NITZSCHIACEAE
NITZSCHIA Hassal, 1845
Nitzschia scalaris (Ehrenberg, 1841 (1843)) W. Smith, 1853
Fig. 13, 4.
W. Smith, 1853, pl. 14, fig. 115.

Van Heurck, 1896, p. 391, pl. 32, fig. 894; Hustedt, 1921 *in* A. Schmidt *et al.*, 1874-1959, pl. 333, figs 1-3; Hustedt, 1930b, p. 409, fig. 783
1841 (1843) *Synedra scalaris* Ehrenberg, p. 425, fig. 18, pl. 2, fig. 2.
Occurrence. Bowan Downs.
Remarks. The Nitzschiaceae are notable for their absence from the Miocene deposits of eastern Australia and this one occurrence was found in only one sample from the

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Fig. 13. 1-3. *Pinnularia* sp. af. *major*, UNEF15587e, West Haldon. 1,2, detail of central area; 1, external focus, 2, internal focus; note stigmata near central fissure of the raphe. 3, valve view.
4. *Nitzschia scalaris*, UNEF15802, Bowan Downs, polar fragment of valve and girdle bands in girdle view.
5. *Eunotia pectinalis*, UNEF15693, Bells Mountain, detail of valve.
6-8. Sponge scleres. 6, UNEF15592, West Haldon. 7, UNEF15593, West Haldon. 8, UNEF15565, Wyrallah.
Transmitted light micrographs, Nomarski DIC; all scale bars 10 μm.


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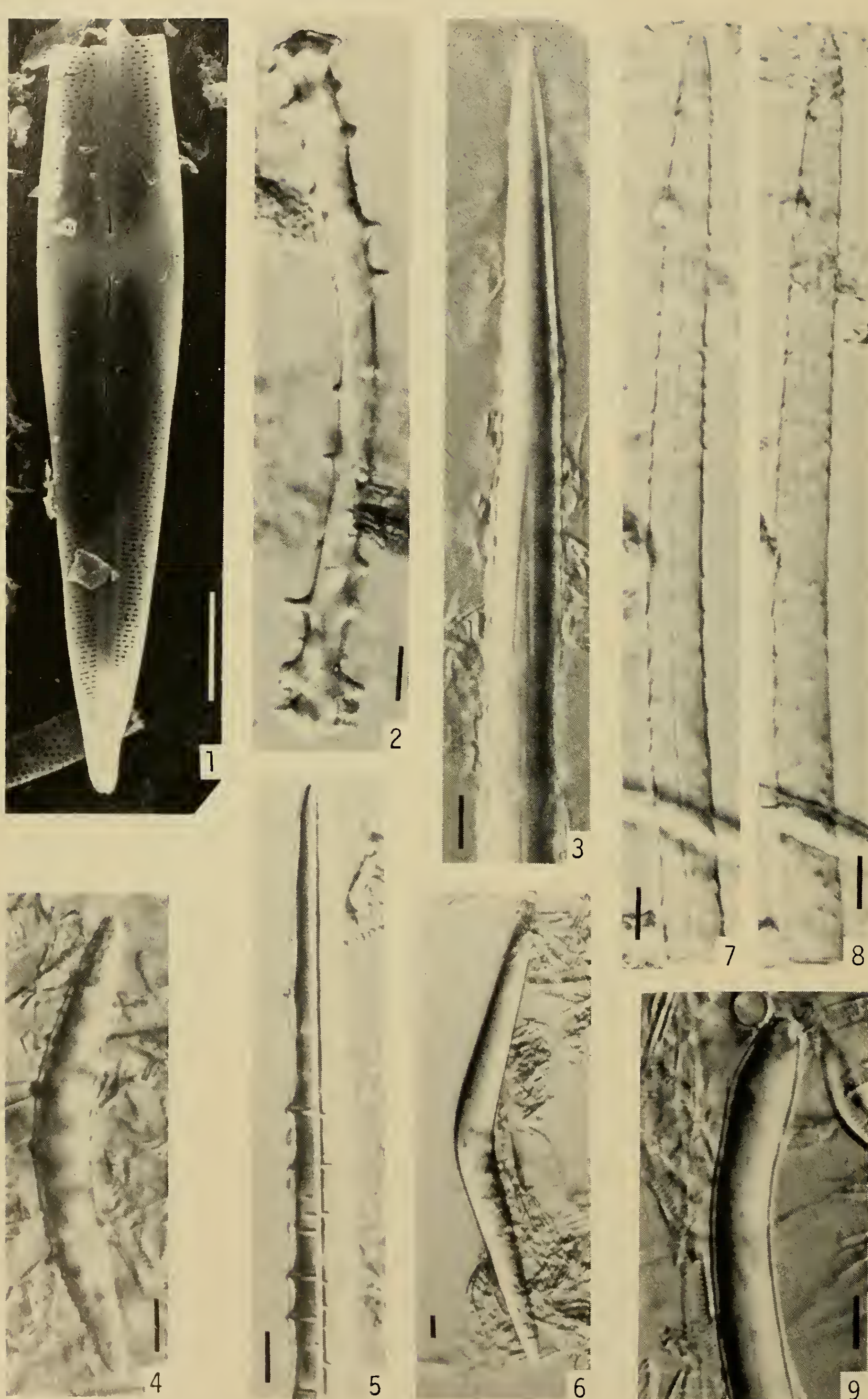
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locality. *Nitzschia scalaris* was characterized by Hustedt (1930b) as a salt water form but also has been found in fresh to brackish water peat deposits by Hanna (1933) and is therefore not useful as an environmental indicator.

Concluding Remarks

The diatom assemblages observed in this survey of Tertiary diatomites are very similar to those observed in non-marine diatomites from North America (e.g. Abbott and Van Landingham, 1972; Andrews, 1966, 1970, 1971; Lohman and Andrews, 1968; Van Landingham, 1964, 1967), Japan (Okuno, 1952) and Europe (Ehrenberg, 1854; Pantocsek, 1892). The marked difference is the relative paucity of taxa in eastern Australian diatomite assemblages.

There are several taxa which have not been observed in this study but which have been recorded from the deposits studied. Skvortzov (1937) recorded the presence in the Middle Flat deposit of three marine species, *Melosira sulcata* (p. 178, fig. 20), *Coscinodiscus subconcavus* (p. 179, fig. 22) and *C. wittianus* (p. 178-179, fig. 26) but we have found no evidence for these species or for any marine influence on the fossil assemblages. Crespin (1947) recorded *Epithemia turgida* (Tintenbar), *Cocconeis* sp. (Wyrallah) and *Neidium* sp. (Chalk Mountain) and again these have not been observed here.

Quite a variety of freshwater sponge spicules (Porifera: Spongillidae) were observed in all diatomite samples (Fig. 13, **6-8**; Fig. 14, **2-9**). Because of the disaggregation and dispersion of scleres and possibility of extinct forms being present, confident identification of the species would require further detailed study. However species of the genus *Radiospongilla* Penney and Racek 1968 seem to be the most prominent, with possible representatives of *Ephydatia* Lamouroux emend. Penney and Racek 1968 and *Heterorotula* Penney and Racek 1968 also present (see Penney and Racek, 1968; Racek, 1969, 1974; Stanisic, 1979).

Acknowledgements

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Fig. 14. 1. Scanning electron micrograph of *Stauroneis frauenfeldiana*, Tintenbar, incomplete valve.
2-9. Transmitted light micrographs, Nomarski DIC, of sponge scleres. 2, UNEF15579, 5, UNEF15571, Tintenbar. 3, UNEF15618, 4, UNEF15627, 6, UNEF15625b, 9, UNEF15588, West Haldon. 7,8, UNEF15553, Wyrallah; 7, median focus, 8, surface focus.
Scale bars all 10 μm.

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